Future Directions in International Science Education

Patrick Holmes

Introduction

"IT SEEMS REASONABLE to begin a discussion of education with a working definition: "The soul and spirit of education is that habit of mind which remains when a student has completely forgotten everything he or she has been taught."

Clearly, using one's education in a specific scientific or engineering context requires a set of abilities which are acquired in various ways; in the present discussion we are concerned with university education, the components of which can usefully be defined in a number of sectors, noting that these sectors overlap and need to be combined in practical situations. The sectors can be defined as: Knowledge; Know-how; Skills; and Understanding.

Knowledge

Knowledge is defined as memorized information that can be recalled for use in specific situations. It is important to note that such information does not necessarily remain valid with time; data becomes redundant as it is superseded by more up-to-date information, and access to factual information is now much facilitated by computer databases. In recent years the extent of the (factual) knowledge-base required by students has been noticeably reduced in many science and engineering courses, effort being redirected to the ability to use data bases effectively.

Know-how

Know-how is defined as the ability to carry out a task or solve a problem, generally acquired through experience; it provides capacity to extend that experience in an innovative way within current practice. In the absence of understanding, know-how cannot be applied to situations beyond current practice.

Skills

Skills can be defined as the ability to carry out a complex sequence of actions that are learned by instruction, demonstration, and practice. Some skills are more self-contained than others (e.g., typing, spelling, and so forth). Others are far more complex, such as design, interpersonal skills, decision making, and communication.

Understanding

Understanding in a science and engineering context is the appreciation of conceptual models of the behavior of systems and their validity; it is in applications that understanding is combined with skills, knowledge, and know-how-in varying degrees to reach a solution to a problem. It is, in a sense, the opposite of intuition which, by definition, lacks logic.

Thus in science and engineering there are fundamental concepts that need to be understood and that, importantly, allow extension to new situations when combined with knowledge, know-how, and the appropriate skills. These sectors have been termed the "cognitive domain of learning" (ref. EPC 8, 1996).

Science and Engineering Education

In university education, it is the variety of balance between these sectors that results in differences in the type of degree or diploma being presented by different institutions. Some concentrate on providing an education which is maximized in preparing a student for employment within current practice. Others prepare students less well for current practice but with a greater expectation of the need to innovate beyond current practice in their employment. It is in the latter case that considerable weight is given to the influence of research on the educational process in the encouragement and practice of innovation. It is notable that the engineering council in the United Kingdom uses the phrase "beyond current practice" to identify the capabilities of those who are or may become chartered engineers.

Other important elements in the educational process and which are termed the "affective domain of learning" (ref. EPC 8, 1996) are motivation; attitude-personal qualities; values-moral, societal, aesthetic. The ways in that these affective domain sectors are developed are not fully understood but they seem to be acquired by the example of others, by experience, by project activities that involve social, moral and aesthetic factors and via the media.

The integration of both the cognitive and affective domains is a skill in itself, termed "integrative thinking," and which is seen to be of particular importance in science and engineering in a design context, but it is presumably equally important in other disciplines. It requires very careful design of project work to illustrate to students the need for and the value of this complex combination.

If these are the essential components of science and engineering education, one needs to query the balance between them in two senses: that of providing the best opportunity for students to educate themselves and that of the perceived needs of industry. The latter has been the topic of numerous conferences and symposia and there seems to be no clear answer-probably because there is no unique answer and industry in an integral sense cannot, therefore, provide one. Thus it becomes the responsibility of the academic community to define those needs.

At the present time there are several key factors that influence science and engineering education. Industry and commerce are more dynamic than ever, the rate of change is very high and most young people expect to change their occupation relatively frequently. Thus the skills acquired at university need to be readily transportable. Additionally, many modern industrial developments require interdisciplinary, teams of which an obvious example is the requirement for environmental considerations in design and applications. Innovation is a key element in all engineering activity and it therefore becomes a key feature in the educational process.

These factors-transportability, interdisciplinarity, and innovation-were the dominant criteria identified in a recent conference on the future of engineering education in Europe (CESAER 1996), together with a need to encourage the development of life-long learning skills.

It would be most beneficial to develop a definition of transportable skills for which the criteria are wide applicability and relative invariance with time-they are fundamental. Mathematical skills must surely be the basis for such a definition but need to be set in an applied context. An example is the understanding of systems dynamics, subject to random or defined excitation and the skills of formulating problems in that context (e.g., the effective "inertia" and "damping" characteristics of complex systems).

In science and engineering, personal and professional skills--communication, interpersonal, team working, decision making, and so on are all transportable and essential.

Interdisciplinary education is a difficult topic. In the past, the provision of courses outside the student's own discipline has been thought to provide some experience in this respect. However, one must query the efficiency of this since in the end it could lead to trivialization of topics and the education of generalists without sufficient depth of education in any one discipline. There may indeed be a place for this form of education but there is merit in attempting to analyze the skills required in interdisciplinary work-in which many academics are involved as consultants to the profession.

It is clear that the modern trend toward teamwork has at its roots the need to combine differing skills; in fact, interdisciplinary and teamwork might well be regarded as synonymous. We might, therefore, gain greatly from the considerable expertise and experience which some sectors of the profession have in this respect. An ability to "speak the language" of a colleague who is expert in another discipline is clearly important, but what "linguistic" knowledge is necessary? if, for example, one does not fully appreciate the implications of an aerobic process, it is a small matter for an expert colleague to present the key features. Thus in an interdisciplinary context the ability to listen is a key factor; to interpret the input in relation to one's own domain of expertise, to respond with the key features of that domain and to conduct an interaction between the team members at a very high level of expertise are essential features. Does a student's taking a number of courses from another discipline encourage the acquisition of these skills or are there better ways?

Innovation is an elusive concept and much discussion has centered on whether it can be taught. From one's own experience, it is quite possible to place students in situations which require innovation in a relative sense; in the sense of requiring to take actions beyond their present level of personal experience and practice. Such exercises require the student to hypothesize solutions to problems which they have not previously experienced, by building on their existing knowledge, understanding, and know-how in a domain of new, innovative actions. Interaction with academic staff who have a higher level of experience allows the development of exploratory and innovatory attitudes and, importantly, the confidence to try!

Life-long learning skills seem to have been the subject of limited investigation, but one would expect that a good university education would inculcate the essential learning skills required for a lifetime of self-education. If may be that motivation for the maintenance and development of skills is the key factor in this regard.

The International Dimension

There has been much discussion in Europe about the "European dimension" in education and specific measures have been adopted to encourage this sector. Of particular success is the exchange of students between universities in different countries of the European Union under a scheme known as ERASMUS-soon to be superseded by the SOCRATES program.

As an example, all science and engineering degrees in Imperial College can now be taken "with a year abroad"-either the third or fourth (final) year of study. It is a requirement that students taking this route are fluent in the language of their host university prior to departure and that they study on a par with their fellow students in the host institution. Academic performance criteria and data are transferred to the home institution at the end of the year and assimilated into the student's overall performance via a scheme known as the European Credit Transfer Scheme, ECTS. This scheme has been the subject of a pilot experiment in the field of mechanical engineering and has proved successful; it is finding wide acceptance and is gradually being adopted for engineering courses throughout Europe, despite some difficulties in relation to national and individual university procedures. The process adds significantly to the mutual recognition of university qualifications across Europe and may well, in time, form the basis of a European accreditation system.

The ERASMUS program gives students and staff valuable experience in the educational and social context of a different country, which is fully valid in its own right for many obvious reasons. However, one would query the extent to which this year abroad is used in a conscious development of the skills required of scientists and engineers who will operate at an increasingly international level. There seems to have been limited analysis of the knowledge, know-how, understanding, and skills set that underlies this activity. Could the year be treated more objectively as a "laboratory" in these educational sectors which would then more easily constitute transportable skills-in this case literally from one country to another? It may be the author's discipline of civil engineering, which is extremely international, which encourages this proposal.

These student (and academic staff) mobility programs are highly commendable for the x percent of students able to study abroad. It is essential to consider the (100-x) percent who cannot have the advantage of that experience. International summer schools provide an alternative but need appropriate and not insignificant funding; it is, therefore, necessary to consider how some degree of international experience might be gained by those who cannot travel. New media facilities in support of education may offer a solution, however partial that may be, and it is very clear that motivation is a key element in the success of such initiatives. Basing such a course or courses on the skills-development objective may illustrate the professional benefits to students and thereby enhance motivation.

Summary

It is helpful to base any discussion of education developments in science and engineering on a set of reasonable elements such as knowledge, know-how, skills, and understanding.

The basic assets of graduating students must be transportable between disciplines and countries in view of the dynamics and international nature of modern industry. These assets include transportable skills, interdisciplinary capabilities, innovative attitudes, and the potential to apply affective domain components-attitudes, and values-in previously alien contexts.

The international dimension of science and engineering education is of paramount importance and merits serious consideration of the coherent skill set that is required to allow scientists and engineers more readily to transport themselves and their work to other locations in the world.

The ERASMUS experience in Europe has been of direct benefit to students and to academic staff in gaining experience in other countries and thereby broadening their international outlook. It would be beneficial to seek ways of extending the European scheme to wider international participation.

Interdisciplinary studies, clearly valuable in their own rights, might well be better implemented if based on a clearer indication of the key skills required to work in an interdisciplinary context, with strong parallels to team-work.

Whatever the optimum balance of educational components, it is important to remember that the most important assets we can give to young people are confidence in their abilities and a willingness to innovate. Maybe the academic world should be more willing to innovate in its educational objectives!

References

EPC 8, 1996: “Open Learning in Engineering Education,” Engineering Professors’ Council, Occasional Paper No. 8, March 1996. c/o Dept. Civil and Mechanical Engineering, University College, Gower Street, London, WC1E 6BT, United Kingdom.

CESAER 1996: Conference on “engineering Education in Europe—The Future with Socrates,” December 1996, Université Catholique de Louvain-la-Neuve, 1348-Louvain, Belgium.

